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STRUCTURE IN THE $Al^{27}(n, \alpha)$ CROSS SECTION

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ABSTRACT

The excitation function for the $Al^{27}(n,\alpha)$ cross section was measured from 12.8 to 14.3 Mev. The energy resolution of the data is better than 80 kev, and the statistical errors are less than 1 percent. The data show a peak at 13.55 Mev in the cross section with a width of about 300 kev and an amplitude of about 4 percent of the average cross section in this region.

SUMMARY

The Problem

Recent developments in nuclear theory suggest that neutron reaction cross sections in the several Mev range may contain a previously unobserved fine structure-fluctuation with widths of the order of 100 kev. Almost all of the available experimental data are too coarse to resolve such structure. To search for such structure, a high-resolution, high-precision measurement of the $Al^{27}(n,\alpha)$ cross section vs. neutron energy was performed over an energy range of 12.8 to 14.3 Mev.

The Findings

A peak in the $Al^{27}(n,\alpha)$ cross section was found at 13.55 Mev. The width of the peak is about 300 kev and the height of the peak is about 4 percent of the average cross section in this region. The fluctuation is probably one of two effects predicted in recent theory. Further experiments, which should better define the origin of the fluctuations, are planned.

INTRODUCTION

Until recently, it had been assumed that nuclear cross sections would not exhibit structure over small energy intervals for energies high enough so that the average widths of the compound nucleus levels greatly exceeded their spacing. However, recent theoretical developments indicate that certain types of cross sections may exhibit structure in this energy region.[1-6] Experiments have verified such structure.[7-10] Because of these developments we decided to re-examine the $Al^{27}(n,\alpha)$ cross section in the 14 Mev region. Previous studies of this cross section[11-15] were performed to establish the magnitude of the cross section and its gross behavior with energy. Neither the errors, energy spacings, nor energy resolutions of the measurements were small enough to establish structure. The data of Gabbard and Kern[11], however, suggest a peak in the $Al^{27}(n,\alpha)$ excitation function at about 13.5 Mev. We chose to study this particular cross section partly because of this indication. Also, the decay characteristics of the reaction product, Na^{24}, make it easy to study the cross section by the activation technique. The 13 to 14 Mev energy region was chosen because good energy resolution can be obtained there, and again because of the suggested peak at 13.5 Mev in the data of Gabbard and Kern.

Our data show that a peak does occur in the excitation function. In the next section we describe the experiment and results, and in the last section we discuss some possible interpretations of the results.

EXPERIMENTAL PROCEDURE AND RESULTS

Neutrons in the 13 to 14 Mev range were produced by the $T(d,n)He^4$ reaction. Deuterons with a 1.630 Mev energy were produced with a Van de Graaff accelerator. The deuteron energy was controlled

by bending the deuterons 90 degrees in a magnetic field. The magnet was calibrated using the thresholds of the $Li^7(p,n)$ and the $T(p,n)$ reactions. The magnetic field strength was measured using a Hall-effect detector. A feedback system on the output slits of the magnet stabilized the Van de Graaff voltage.

The deuterons bombarded a titanium tritide target 2 mg/cm^2 thick. In part of the experiment the target was perpendicular to the beam, and the rest of the time it was slanted 45 degrees with respect to the beam. In the first geometry, the target thickness to the deuterons is 260 kev, and in the other geometry it is 370 kev. Hence, the energy spread of the interacting deuterons is $\pm$ 130 or 190 kev.

In each exposure 24 samples were exposed at different angles with respect to the deuteron beam, corresponding to different neutron energies. Each sample is an aluminum cylinder 0.64 cm in diameter and 2.54 cm long. They were placed on the sample holder with their axes perpendicular to the direction of the deuteron beam. The sample holder consisted of a flat surface 6 inches long which was positioned with an error of less than 1 mm with respect to the sample holder. The average distance of the samples from the target was about 25 cm. The deuteron beam itself was focused to form a line on the target parallel to the axes of the samples. The length of the line formed by the beam was 2.5 cm, and its width was less than 0.3 cm.

The samples were irradiated for several hours, and were then counted with a gamma-ray counter to determine the relative amount of Na^{24} in each sample. The gamma counting was done with a 7.6 cm high, 7.6 cm diameter NaI(Tl) crystal which has in it a 2.5 cm diameter, 2.5 cm deep well. Each sample was placed in the well and counted for either 20 or 30 minutes. Counting all the samples took about 12 hours, or less than one half life. The NaI(Tl) crystal output was recorded with a 100-channel analyzer, and only pulses corresponding to gamma rays from 1 to 3 Mev were used in the analysis of the data. For each sample about 10,000 counts were recorded, with a background of 1,110 counts per 30 minutes. The spectrometer system was checked for drift before and after each sample run. The drift correction was always less than 0.1 percent.

The gamma counts were corrected for the inverse square distance from the tritium target, sample weight, decay of Na^{24}, and the variation of the $T(d,n)$ cross section with angle. The data of Bame and Perry[16] were used for this last correction. These corrected counts give the relative cross section as a function of neutron energy.

Five exposures were made. The first two exposures had low neutron yields, and the statistical counting errors were several percent. These data were not used since 1 percent statistics were obtained on the last three exposures. Of the three exposures used, two were made under "identical" conditions, to improve the statistics and check the reproducibility. The data agreed within the statistical accuracy, and are shown as the open circles in Fig. 1. In the last exposure, as many as possible of the experimental conditions were changed to check against possible sources of error. A different target and target assembly were used, and the target angle was changed from perpendicular to 45 degrees with respect to the beam. The position and orientation of the sample holder with respect to the target also were changed. These data are shown as the solid circles in Fig. 1.

The error bars in Fig. 1 represent only the statistical error. Other sources of error are all estimated to be well under 1 percent. The errors due to sample positioning and uncertainty in beam position should be less than 0.2 percent. In particular, a consistent beam positioning error, which would enter into the inverse square correction, would tend to reduce the peak at 13.5 Mev instead of producing an artificial peak. Positioning errors would also produce an uncertainty in angle which could shift the entire energy scale by 20 kev. However, the relative energies of the points would not change more than a few kev. Errors in the deuteron energy would expand or contract the energy scale by 10 to 20 kev at the extremities, with much less effect on the interior of the curve. In any case, the shape of the curve would be virtually unchanged.

The width of the energy resolution curve is determined by the angle subtended by the sample at the target (and vice versa) and the deuterium energy loss in the target. The energy control of the machine is such that variations in the energy of the incident beam itself are negligible. The standard deviation of the neutron energy distribution for the point at 12.816 Mev is 29 kev; for the point at 13.509 Mev it is 25 kev, and for the point at 14.282 Mev it is 41 kev. The energy resolutions for the other points vary smoothly between these extremes. Note that the energy spread (two standard deviations) is somewhat larger than the spacing between the points, but much smaller than the width of the peak at 13.5 Mev.

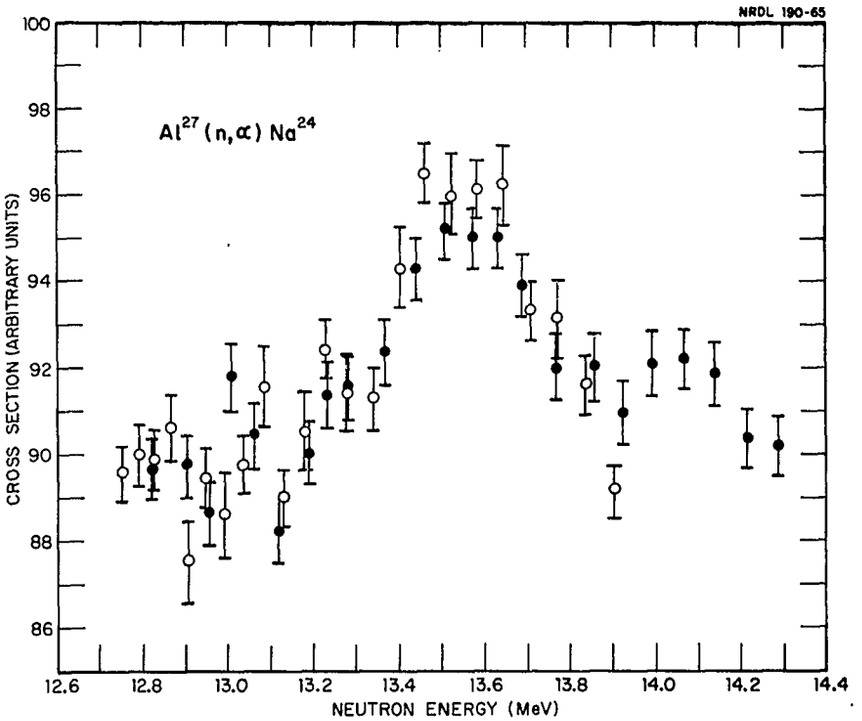

Fig. 1 Relative excitation function for the $Al^{27}(n,\alpha)$ cross section. Note the suppressed zeros on both scales. The open circles and solid circles represent data taken under different experimental conditions. The energy spread for each point is roughly equal to the spacing between open (or closed) points. The error bars represent only the standard deviation due to counting statistics. However, other errors are estimated to be small compared to the statistical error. The uncertainty in the energy scale is of the order of 20 keV, but the uncertainty in the relative energies of the different points is much smaller. The scatter of the points in the 13.1 MeV region is probably experimental error.

DISCUSSION

The data establish the existence of a bump in the excitation function at 13.5 Mev, with a width of about 300 kev and an amplitude of about 4 percent of the average cross section.

For energies as high as those used here (compound nucleus excitation energies from 19.5 to 22.0 Mev) the widths of the compound nucleus levels should be much larger than the average level spacing. In other words, we are in the "continuum" region. It is not immediately apparent, therefore, why a peak like that observed should occur.

Two mechanisms for producing structure in nuclear excitation functions have been proposed recently. One theory, proposed by Ericson and others,[1-3] suggests that interference between overlapping compound nuclear levels will produce fluctuations with spacings of the order of the widths of the compound nuclear levels. This theory appears to be consistent with a great deal of reaction data for high compound nucleus excitations. However, the fluctuations should be highly damped for a cross section integrated over angle and summed over many residual levels, and it is an open question whether even a 4 percent fluctuation is reasonable for the total (n,α) cross section. A quantitative prediction based on the Ericson theory requires a knowledge of the α-particle transmission coefficients and spins for all the significant levels of the residual Na^{24} nucleus; such an evaluation is not feasible at present because of lack of data on the spins.

An alternative mechanism for producing structure is suggested by Block, Feshbach, Kerman, Rodberg, Young, and others.[4-6] In this mechanism, resonances are caused by the incident nucleon raising one or a few nucleons to excited states. The theory has not been developed to the point where quantitative predictions can be made for our reaction.

Fortunately there exists a clear test between the two mechanisms. For the first mechanism, there should be no correlation between the fluctuations in different cross sections for decay of the same compound nucleus. Hence the observed peak would not be expected in the Al^{27} total cross section of the $Al^{27}(n,p)$ cross section, for example. In the second mechanism, on the other hand, the peak should appear to some extent in all the $Al^{27}(n,x)$ cross sections, since the mechanism is associated with the formation of the compound nucleus. It is planned to look for this structure in one or more $Al^{27}(n,x)$ cross sections.

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